



Resources, Equipment and Logistics in Support of Long-term Monitoring at Fort Benning

by David Leese

BACKGROUND: The Strategic Environmental Research and Development Program (SERDP), Ecosystem Management Project (SEMP), Ecosystem Characterization and Monitoring Initiative (ECMI), <http://www.denix.osd.mil/denix/Public/Library/SEMP/semp.html>, is a long-term, multi-agency monitoring initiative at Fort Benning, GA, to characterize the environment in and around Fort Benning and provide long-term databases documenting the environmental (meteorological, hydrological, biological and geographical) conditions in the ecosystem. In 1999, as part of this program, the U.S. Army Engineer Research and Development Center (ERDC), Environmental Laboratory (EL), deployed ten meteorological stations, four surface water stations, and four groundwater stations to support the SERDP, SEMP, ECMI long-term monitoring program.¹ This monitoring program is expected to continue for at least 10 years and be a prototype for long-term monitoring programs at other military installations.

PURPOSE: The purpose of this technical note is to report the progress, status, and lessons learned during implementation and monitoring of the environmental data acquisition systems in support of the Long Term Monitoring Initiative. The LTMI is sponsored by the Strategic Environmental Research and Development Program (SERDP) study at Ft. Benning, GA. One purpose of the LTMI at Fort Benning is to develop historical databases for meteorological, surface water, and groundwater stations utilizing these data acquisition systems. For a full description of LTMI, (ECMI), refer to Kress (2001).²

SITE SELECTION: Site selection was influenced by mission demands, scientists' requirements, areas of study, equipment performance, and limitations. The effort to historically document needed environmental parameters concentrated on particular watersheds across Ft. Benning with the installation of meteorological data acquisition systems in ten of the watersheds. Actual site selection requirements included access to open areas that would allow unimpeded wind monitoring, no natural or man-made structures that would impede solar radiation sensors, and no large paved or otherwise improved areas that would influence air temperature measurements and line-of-site access to cell phone transceivers for data retrieval. Sensor manufacturers, state climatologists, and the EPA provide standards, guidelines, recommendations, and requirements for environmental sensor placement relative to the surrounding area. Consideration was also given to visibility and access in light of vandalism and theft. Figures 1 and 2 indicate names and placement of the stations across Ft. Benning.

¹ Hahn, C.D., and Leese, D.L. (2002). "Automated Environmental Data Collection at Fort Benning, Georgia, from May 1999 to July 2001," ERDC TR-02-3, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

² Kress, M. R. (2001). "Long-Term Monitoring Program, Fort Benning, GA; Ecosystem Characterization and Monitoring Initiative, Version 2.1," [ERDC/EL TR-01-15](http://www.denix.osd.mil/denix/Public/Library/SEMP/semp.html), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

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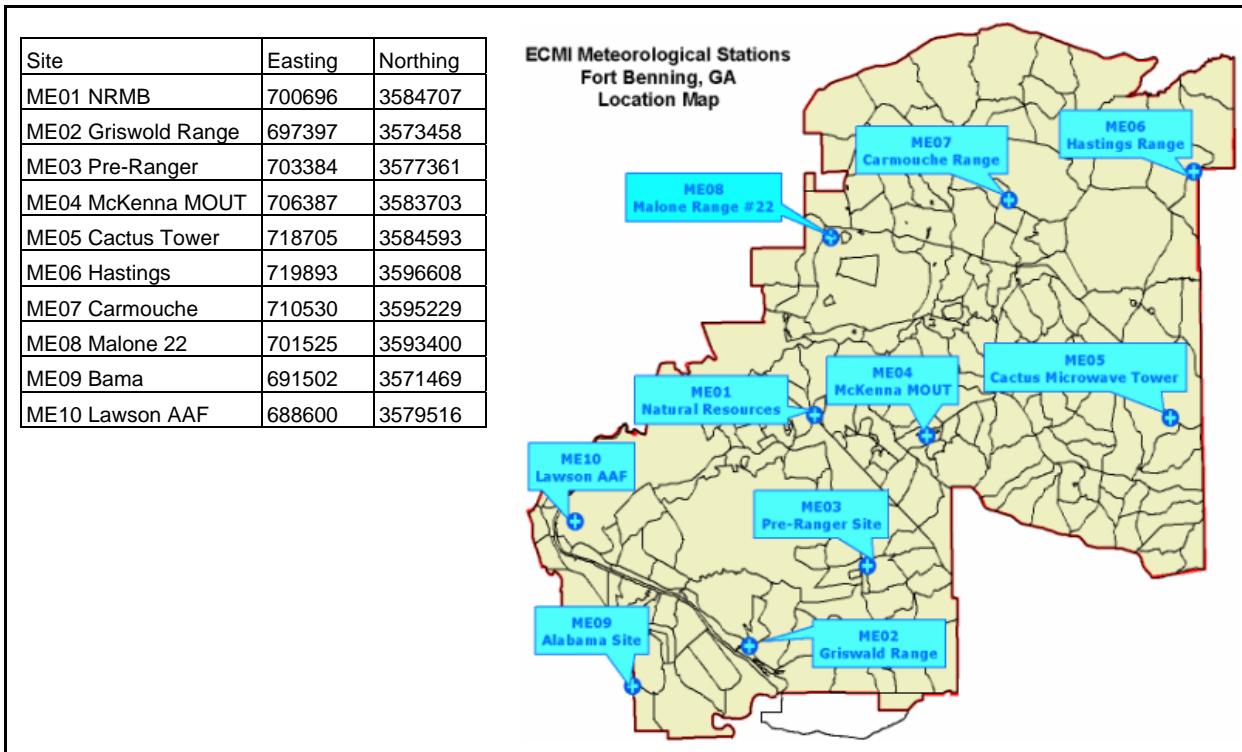


Figure 1. Map of meteorological data collection stations

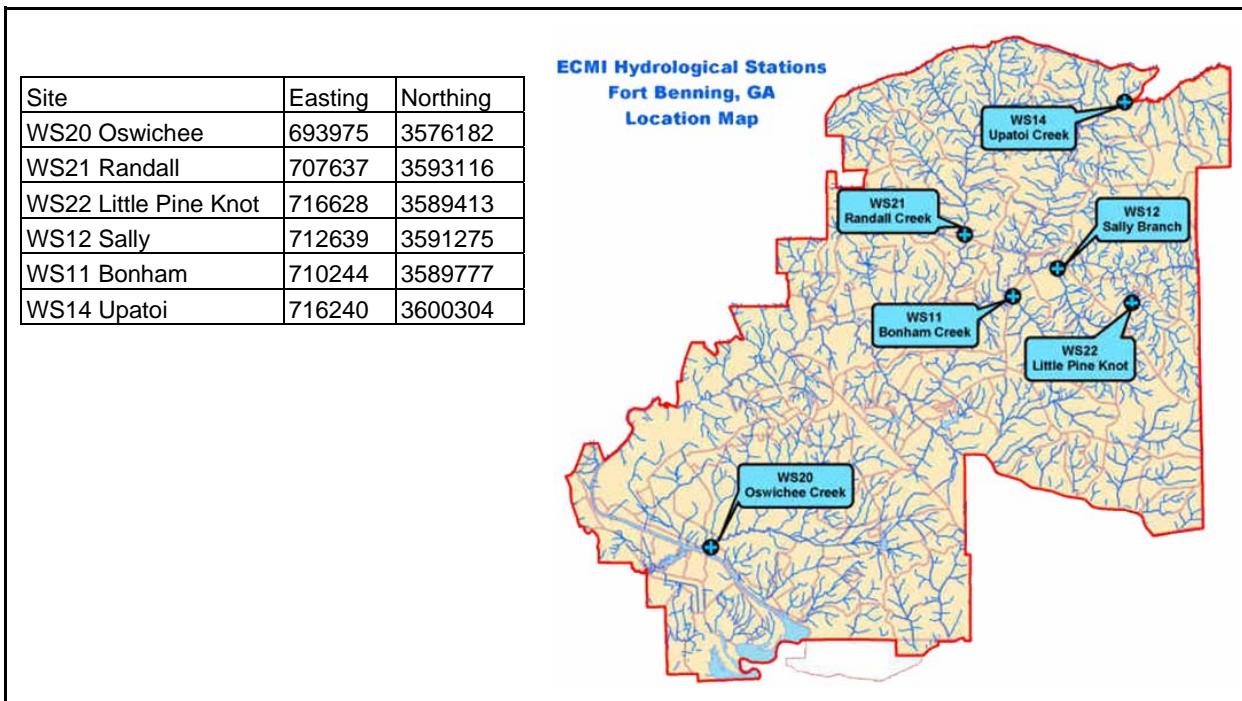


Figure 2. Map of the surface water data collection stations

EQUIPMENT CHOICES: Equipment choices were made with off-the-shelf sensor compatibility, flexibility, and reliability as major concerns. The datalogger chosen for nine of the ten meteorological sites, the Campbell Scientific CR10X, is the latest generation datalogger and offers the programmability and flexibility required for long-term data acquisition. The tenth meteorological datalogger is a Campbell Scientific CR23X, which differs from the CR10X by increased sensor channel inputs. This logger choice is necessary for the site at the Natural Resources office, ME01, which has the added parameters of evaporation with associated sensors. All meteorological sites have cell phone access for data retrieval and any software driven maintenance.

Sensor selection consists of the standard complement of meteorological interests: air temperature, relative humidity, barometric pressure, global solar radiation, wind speed, wind direction, and precipitation. Each of these sensors directly interfaces with the CR10X to minimize hardware and software compatibility conflicts.

The dataloggers are programmed to record and store each of these parameters on 30-min intervals with data retrieval occurring daily. Table 1 lists specific meteorological equipment used with current prices. A typical meteorological data acquisition station is shown in Figure 3.

Equipment used in collecting surface water data is similar to the meteorological equipment as far as datalogger, power supply, and storage media. Sensor selection includes stream water flow, level, and temperature. The dissolved oxygen parameter has been added to the Sally Branch station, WS12, and will be included on the other water stations in the near future. As with the meteorological stations, these sites are programmed to collect and store data every 30 minutes. Of three current stations, one has a cell phone data link for daily retrieval. Table 2 lists equipment and sensors used for surface water monitoring with current costs. A typical surface water monitoring station is shown in Figure 4.

Information on surface water quality is obtained manually on two-week intervals. Parameters include dissolved oxygen, percent dissolved oxygen, conductivity, pH, temperature, level, and turbidity. Unattended water quality sensors have a tendency to foul due to contaminants and biological growth, making automated data collection difficult. Newly developed



Figure 3. Typical meteorological data acquisition station



Figure 4. Typical surface water monitoring station

Table 1 Equipment and Costs for a Typical Meteorological Data Acquisition Station Using Campbell Scientific¹ Equipment				
Description	Part Number	Qty.	Each	Total Cost
Power supply	20 Ahr Gel Cell	1	\$230.00	\$230.00
Regulator	CH12R	1	\$185.00	\$185.00
Enclosure	ENC 16/18 - 10628	1	\$270.00	\$270.00
Solar panel	MSX10	1	\$200.00	\$200.00
Tripod	CM10	1	\$345.00	\$345.00
Radiation shield	41002	1	\$173.00	\$173.00
Air temp/humidity	HMP45C-L6	1	\$550.00	\$550.00
Barometric pressure	CS105	1	\$575.00	\$575.00
Pyranometer, global	LI200X-L12	1	\$280.00	\$280.00
Pyranometer base	LI2003S	1	\$55.00	\$55.00
Pyro. mtg. arm	015ARM	1	\$75.00	\$75.00
Wind monitor	05103-L15	1	\$875.00	\$875.00
Precipitation	TE525MM-L10	1	\$360.00	\$360.00
CR10X ²	CR10X-2M	1	\$1,309.50	\$1,309.50
Key pad ³	CR10KD	1	\$266.75	\$266.75
Storage module	SM16M	2	\$600.00	\$1,200.00
Storage module mount	13690	1	\$16.49	\$16.49
Software	LoggerNet	1	\$300.00	\$300.00
Crossarm	019ALU	1	\$74.00	\$74.00
Communications pkg		1	\$700.00	\$700.00

¹ Campbell Scientific, Inc., 815 West 1800 North Logan, UT 84321-1784, 435-753-2342 FAX: 435-750-9540
www.campbellsci.com

² For CR23X option add \$994.25.

³ Keypad CR10KD would not be required with CR23X option.

Table 2 Equipment and Costs for a Typical Surface Water Monitoring Station Using Campbell Scientific Equipment¹				
Description	Part Number	Qty.	Each	Total Cost
VMT velocity sensor	VMT1	1	1,520.00	1,520.00
Druck Level Sensor	CS-420	1	580.00	580.00
Temp sensor	107	1	80.00	80.00
Power supply	20 Ahr Gel Cell	1	230.00	230.00
Regulator	CH12R	1	185.00	185.00
Enclosure	ENC 16/18 - 10628	1	270.00	270.00
Solar panel	MSX10	1	200.00	200.00
Tripod	CM10	1	345.00	345.00
CR10X	CR10X-2M	1	1,309.50	1,309.50
Key pad	CR10KD	1	266.75	266.75
Storage module	SM16M	2	600.00	1,200.00
Storage module mount	13690	1	16.49	16.49
Software	LoggerNet	1	300.00	300.00
				\$6,502.74

¹ Campbell Scientific, Inc., 815 West 1800 North, Logan, UT 84321-1784, 435-753-2342, FAX: 435-750-9540,
www.campbellsci.com

sensors are being evaluated that may allow the option of installing automated stations for this purpose. Table 3 lists equipment currently being used to collect surface water quality information.

Several groundwater wells were installed across the installation to monitor groundwater levels and temperatures. Wells were developed to a depth of 30 ft and a recording pressure/temperature sensor was lowered into place. Level data are referenced to the top of the well casing, which is MSL documented. Table 4 illustrates sensor manufacturer and product information for the sensor used in the groundwater wells.

SYSTEM INSTALLATION: Prior to installation of the data collection stations, some of the components were assembled in the enclosure. This would include the installation of the datalogger, the power supply and regulator, installation of the cell phone, cell phone antenna cable and modem, installation of the barometric pressure sensor, attachment of the remaining sensors to the datalogger, and programming of the datalogger. This work is more efficiently performed “on the bench” and the sensors can be packaged so that they may be left attached for transit to expedite installation.

The datalogger is programmed using the appropriate instruction set for each sensor type. The instruction set is similar from site to site with expected differences being site identifiers and calibration corrections for barometric pressure and wind direction sensors.

After site selection, the data acquisition system is installed using standard procedures and manufacturer’s instructions and recommendations. The tripod is erected, securely anchored, and a ground rod is installed. The fiberglass equipment enclosure with the previously mounted datalogger inside is secured to the mast. The various sensors are attached to the mast utilizing the appropriate sensor housings and mounts. The remaining associated leads are attached to the previously assigned channel inputs on the datalogger.

The solar panel is installed last, affixed to the mast, oriented towards the south, and connected to the regulator. The cell phone antenna is attached to the mast and, using a signal strength indicator, is oriented towards the nearest cell tower for maximum signal strength.

When mounting the Vaisala HMP45C air temperature/relative humidity sensor, the gill radiation shield should be positioned so that the sensing element is 2.0M (EPA), from ground level.

Table 3
Equipment Used for Surface Water Monitoring, Hatch/Hydrolab¹

Model: Datasonde 4A Multiprobe with temperature, DO, DO circulator, pH, level, turbidity, conductivity and other hardware options	\$7,620.00
¹ Hydrolab-Hach Company, P.O. Box 389, Loveland, CO 80539-0389, 1-800-949-3766. http://www.hachenvironmental.com/ .	

Table 4
Ground Well Water Monitoring Sensor, In-Situ, Inc.¹

In-Situ mini-Troll	\$1,795.00
¹ In-Situ, Inc., 210 S. Third Street, Laramie, WY 82070-0920, 1-800-446-7488, www.in-situ.com .	

If the enclosure's sensor cable conduit is to be sealed, the barometric pressure sensor, mounted inside the enclosure, a vent tube will need to be attached and directed to the outside of the enclosure. A ground elevation relative to MSL will need to be ascertained to calculate a correction for barometric pressure.

The global solar radiation sensor, mounted on its arm, should be positioned directly south of the mast to avoid any potential shadow. Care should also be taken in placing the solar panel so that it does not influence the solar sensor in shadowing or reflecting on the sensor.

The R.M. Young wind monitor is installed on its mount, oriented to north as specified in the installation manual, and secured. A check for free movement and correct readings assures operation.

The Texas Electronics precipitation gauge is mounted to the mast above any other mount that may influence the quantity of moisture collected by the gauge. This includes objects that might deflect or splash undesired precipitation into the gauge.

At the Natural Resources site, the standard complement of meteorological sensors is in place as well as a sensor to monitor evaporation rate. To accomplish this requires a sensor that detects change in water level in a large pan of water and a wind speed monitor at water surface to assist in calculating evaporation rate. Pan water temperature is monitored to identify periods of possible sensor freeze that would produce invalid data.

All of the meteorological stations have limited access by a chain-link fence enclosure. This 20-ft by 20-ft by 6-ft enclosure topped with three strands of barbed wire discourages unauthorized access and minimizes potential vandalism while allowing continued data acquisition.

Surface water monitoring sites were placed at six locations across the installation. The placement of this equipment is similar to the meteorological sites with different sensors. Surface water level, flow, and temperature are monitored, recorded, and stored in 30-min intervals.

DATA RETRIEVAL: Data are retrieved from the automated data acquisition systems using several methods. The bulk of the data is retrieved using daily direct contact via cell phone. An automated software application places a call to each of the meteorological stations and one surface water site and downloads all data not collected since the last call. These data are appended to the appropriate data file for further use. This method also allows any software updates or corrections to be uploaded to the datalogger.

Another data retrieval method consists of physically visiting the station, exchanging the data storage media, and utilizing a laptop and interface, downloading the appropriate data for further review. Data can also be retrieved from the datalogger's intermediate storage area by using a Palm PDA and required software.

Two surface water-monitoring sites do not have cell phone data retrieval capability due to extreme range or terrain constraints. The site visits to these locations consist of visual checks of

equipment and sensors for damage or problems. A review of the stored data will reveal sensor performance and any problems will be discovered.

Water well data are retrieved using a laptop and a direct-connect cable to the sensor. While connected, the condition and status of the sensor package is checked and any problems or concerns are addressed.

Data are collected at the four groundwater well sites from the In-Situ mini-troll water level sensors utilizing a conventional laptop computer. These data are quality checked and appended to the well site database for inclusion in the data repository. The conditional status of the sensor is checked during this session and points of concern such as sensor battery life, storage used, and file space available are noted and if needed, any repair or replacement is made at this time. Sample meteorological data are shown in Table 5; sample surface water data are shown in Table 6.

SITE VISITS: Routine site visits are conducted on a four- to six-week basis to visually inspect the hardware for physical damage or other obvious defects. Sensor problems noticed in the daily/weekly data checks are corrected on these scheduled site visits. Sensors that exceed their calibration life are exchanged at this visit. On those sites that do not have cell phone data retrieval, data are collected from the on-board storage media and archived for quality check. Any problems found at this time such as sensor damage, power supply failure, or similar problems are rectified.

EQUIPMENT MAINTENANCE: Equipment maintenance consists of assuring that installed sensors are functioning properly and are within their calibration specifications. Sensors with obvious physical damage are replaced and, if feasible, repair procedures are initiated for the damaged sensor. Certain sensors have a manufacturer's expected calibration life span. This fact is noted and the sensor is exchanged with a freshly calibrated unit on schedule. The replaced sensor is then scheduled for return to the manufacturer for recalibration and/or refurbishment as needed.

Sensor, power, and ground cables are inspected for breaks, failures, or damage and repaired or replaced. Securing mounts, sensor mounts, and tripod hardware are periodically inspected and any failure or other problem is rectified. Any vandalism or equipment loss is noted and if necessary, damage or loss is reported to the appropriate law enforcement department for their involvement.

LESSONS LEARNED: Throughout the monitoring period from August 1999 to present several lessons have been learned concerning hardware selection, installation, and implementation as well as equipment performance. All of the data acquisition stations are stand-alone and self-powered systems. This presents the challenge to supply and maintain sufficient power to operate the datalogger and its sensor suite as well as power for cell phone communication. Overall, the meteorological stations have performed almost flawlessly. Problems experienced are described below.

Table 5
Sample of Meteorological Data

Program Number	Calendar Year	Julian Day	Time 24 Hr GMT	Station ID Nat Res	Air Temp Deg C	Relative Humidity Percent	Solar Radiation W/MSq	Barom. Pressure mBars	Wind Spd 2.6 M M/Sec	Wind Dir 2.6 M Deg N	Precip mm	Evap Level mm	Wind Spd Evap Pan M/Sec	H ₂ O Evap Deg C	Battery VDC
123	2004	5	2030	1	18.6	90	65	1022	1.5	284.3	0	23.1	0.4	22	11.89
123	2004	5	2100	1	17.9	90	32	1022	1.2	283.2	0	23.1	0.5	21.8	11.89
123	2004	5	2130	1	16.9	92	17	1022	1.1	284.7	3.7	19.2	0.7	21.4	11.99
123	2004	5	2200	1	15.3	93	10	1023	1.4	299.2	0.2	19	0.7	20.9	11.99
123	2004	5	2230	1	14.4	92	6	1023	1.2	282.7	0.5	18.9	0.4	20.5	11.98
123	2004	5	2300	1	13.8	93	3	1023	0.7	311.8	1.2	17.7	0.4	20	11.97
123	2004	5	2330	1	13.3	94	0	1023	0.9	298.3	0.4	17.3	0.5	19.6	11.97
123	2004	6	0	1	13.1	94	0	1023	0.8	289.7	0	17.3	0.4	19.1	11.96
123	2004	6	30	1	12.9	93	0	1023	1	294.9	0.1	17.2	0.7	18.8	11.96
123	2004	6	100	1	12.1	91	0	1023	0.8	306.1	0	17.2	0.5	18.4	11.95
123	2004	6	130	1	11.6	90	0	1023	0.8	320.1	0	17	0.8	17.9	11.94
123	2004	6	200	1	11.1	89	0	1023	0.9	321	0	17	0.5	17.5	11.94

Table 6
Sample of Surface Water Data

Program Number	Calendar Year	Julian Day	Time 24-hr GMT	Station ID Sally	Water Level M	Water Flow M/Sec	Water Temp Deg C	DO Percent	Battery VDC
125	2004	5	1900	12	0.49	1.69	19.7	102.8	12
125	2004	5	1930	12	0.49	1.79	19.9	102.9	12
125	2004	5	2000	12	0.49	1.78	20	102.7	12
125	2004	5	2030	12	0.49	1.75	20.2	102.4	12
125	2004	5	2100	12	0.49	1.7	20.3	102.3	12
125	2004	5	2130	12	0.5	1.67	20.4	102.1	12
125	2004	5	2200	12	0.5	1.66	20.5	101.7	12
125	2004	5	2230	12	0.5	1.64	20.5	101.1	12
125	2004	5	2300	12	0.52	1.64	20.5	100.5	12
125	2004	5	2330	12	0.54	1.55	20.5	99.6	12
125	2004	6	0	12	0.55	1.55	20.4	98.3	12

Meteorological Problems. A lightning strike at the Natural Resources site damaged the datalogger, wind monitor, and air temperature/relative humidity sensor. The intermittent symptoms exhibited in the data initially indicated damage limited only to the sensors. These were changed and all problems appeared to be resolved but the problem reappeared. A datalogger swap solved the problem and the damaged datalogger was returned to the manufacturer for evaluation and repair where it was determined that the lightning damage prevented total repair with confidence.

At the Natural Resources station, the evaporation sensor also required replacement due to excessive wear in the level's potentiometer. This prevented smooth float travel and produced erratic data. The damage to the potentiometer was evaluated as being caused by normal wear. This sensor was replaced and the faulty component will be repaired by potentiometer replacement.

At Ranger Station ME03, a circuit failure in the cell phone created a short that allowed a power drain on the system's main power supply. This would deplete the battery to the point that the datalogger would not run its scheduled data acquisition routine, instead going into a sleep mode. During daylight hours the station's solar panel would recharge the battery to a level that would permit datalogger operation for a short period of wake time; then, collection would stop in the night hours. Replacement of the cell phone remedied the problem. Neither the datalogger nor any sensors at this station were damaged from this problem.

Alabama meteorological station ME09 also experienced power supply problems but of a different sort. Somewhere in the system a constant power drain consumed power faster than the solar panel could provide it. The usual methods of on-site trouble-shooting were employed to solve the problem and at times appeared to be successful. Diagnosis of the problem was further complicated due to the fact that the problem would not occur until several days after the battery had been exchanged. However, recurrence of the problem persisted. A detailed system check finally discovered that the storage module, used as a means of data storage redundancy, had failed and was the source of the power drain. In over 10 years of experience and use of nearly

100 of these type modules, this is the only instance in which this problem has occurred. The module was replaced and the station continues to operate properly.

The environment at the McKenna MOUT site, ME04, is different than the other sites. The immediate area surrounding this station is used for troop training and maneuvers. This includes occasionally airlifting personnel into the area using helicopters that naturally create periodic clouds of dust and grit. The high incidence of these airborne particles accelerates wear on the wind monitor at this station, requiring more frequent sensor monitoring and exchange.

The sole problem at the Cactus site, ME05, was loosening of the mounting bracket for the solar panel. This allowed the panel to orient itself to a less than optimum position for recharging the power supply. Sufficient power was maintained with no loss of data acquisition and the panel was secured.

The meteorological stations are necessarily located in open areas. As such, the station at Hastings, ME06, is located near the perimeter of a tank training/firing range. In one instance, either from a controlled burn initiated by the forestry section of Natural Resources or from a fire started from artillery rounds, the wind monitor and cables sustained physical damage from the heat. Damage was cosmetic and did not compromise the data. As a note, forestry section personnel of the Natural Resources office are aware of all of the research sites with deployed equipment and make every effort to avoid these areas. In fact, the forestry section personnel retrieve and reference the data from these sites to assist their decisions concerning controlled forestry burn schedules.

Surface Water Problems. Automated unattended data acquisition of water quality parameters has proven to be difficult. The initial proposal included the installation of an unattended multiprobe unit that would transfer its data to the datalogger, which would store the data until retrieved via cell phone. The multiprobe would contain the desired sensors for DO, pH, conductivity, turbidity, and temperature. The data for level, flow, and a second temperature probe are collected from discrete sensors. A problem that became obvious in short order was one of individual sensor degradation due to bacterial buildup and fouling from water contaminants. A series of streamside field site visits were conducted to perform sensor cleaning and calibration checks and to try to establish a maintenance schedule that would provide data within the sensor specifications. Logistically this was cumbersome at best requiring personnel to carry in necessary cleaning supplies and hardware as well as calibration standards, measuring devices, and replacement sensors. The trial included four different sites and over a period of time, it became apparent that each site exhibited a different rate of degradation necessitating different schedules. Also, this routine would be required after each significant precipitation event as the stream level elevated and receded. From these labor-intensive efforts it was determined that the number of site visits necessary to maintain sensor integrity would be cost-prohibitive. It has been decided that bi-weekly visits would provide needed data for water quality information. This includes performing in-lab multiprobe sensor calibration prior to site visits and recording parameter findings from each site.

Stream information regarding level, flow, and temperature will continue to be collected with the automated data acquisition system. The data acquisition record at all sites improved after the

decision was made to exclude the Hydrolab multiprobe from the datalogger. The inherent requirements of the multiprobe, including power and data formats, complicated its implementation.

The surface water data acquisition problem for the first 2-1/2 years (summer 1999 through summer 2001) was complicated by the fact that the Southeast was experiencing a long-term drought, reflected in unusually low water conditions. In some instances at least one of the creeks experienced a no-flow/low-flow state, resulting in stagnant pools and extreme water quality conditions.

Other problems were experienced at Upatoi Creek, Randall Creek, and Oswichee Creek. The equipment at Randall Creek, WS21, sustained the only act of vandalism associated with ERDC property. During the data collection period, cables for the level, flow, and temperature sensors were cut and destroyed and the station equipment was ransacked. Nothing was missing, but replacement sensors were not available and it was decided to remove all hardware until replacement sensors could be acquired. This station is scheduled to be reestablished in the summer of 2005.

The station at Oswichee Creek, WS20, was damaged by an unusually high water level (locals claimed a hundred-year event), which occurred after several days of heavy rains. The creek overbanked and submerged the equipment. Stream levels that usually run 0.5 to 2.0 m went to an estimated 6 m. Two sets of data were acquired at this site and all equipment and most of the sensors were damaged beyond repair. This station is scheduled to be reestablished in the summer of 2005.

Problems at the Upatoi station, WS14, were comparatively minor. When the station was installed, sensor cables were left lying on the ground between the tripod and the sensor housing. At some point, an animal chewed through the temperature sensor cable coating and eventually the conductor. Replacing the sensor and stringing the cables from the tripod to an elevated pipe solved the problem.

The system installed at Little Pine Knot (WS22) required replacement early in the project due to lowland flooding and improper equipment installation. Since replacement, the major problem consists of power supply. Being located in a lowland/valley area surrounded with non deciduous trees decreases solar potential. Monthly site monitoring helps assure adequate power.

Power supply problems were experienced at the Bonham Creek site (WS11) as well. Surrounding vegetation and terrain are similar to Little Pine Knot and similarly, monthly monitoring of the battery helps the data acquisition effort.

Sally Branch data acquisition has continued with minimal problems. It too suffers from power supply problems, but to a lesser degree due to a more open area with better solar access.

Ground Well Problems. Four ground wells were developed across the installation to monitor groundwater levels. These wells are located near existing surface water monitoring stations at Randall Creek, Sally Branch, Little Pine Knot, and Oswichee Creek. A fifth well was attempted

at Bonham but after drilling a 60-ft dry hole, was abandoned. Data from each well are acquired with a permanently placed pressure transducer, mini-troll, which monitors the depth of the water column. This distance is referenced to the top of the well casing. At project outset, the initial procedure for data retrieval from the mini-trolls was to retrieve the mini-troll using the wire rope tether, unscrew the backshell, attach a data interface cable to the mini-troll and a laptop and download the data. This process eventually proved to be problematic due to the connector interface from the data cable to the mini-troll. The physical structure of the connector's contacts is fragile by design and misalignment or damage to the contacts was likely. This connector is a flexible elastomer board, 1.6 cm x 1.25 cm x 0.3 cm, overlaid on three sides with approximately 100 thin-film gold traces. When attaching the backshell or the interface cable, one edge of this board and its thin-film contacts would necessarily physically contact the mating connector, sometimes damaging the thin-film contacts. When the connector board was damaged, a replacement board would be tediously installed and the backshell or interface cable attached. As battery life in these sensors runs one to two years, the only reason to breech the connector/backshell/interface is data retrieval and sensor status. To remedy this problem, an interface cable acted as a tether/interface so the mini-troll can remain in place and retrieve data without problems. To further reduce the chance of connector damage, an in-line battery pack that will increase battery life to seven years is being anticipated. Also, the construction of the connector board has been improved to incorporate a more secure contact bonding process, which should help to decrease problems.

Data Retrieval Problems. The procedure for automated data retrieval via cell phone communication requires a dedicated Windows-based PC with an analog modem and phone line. Due to installation network security issues, the PC used to download data via modem should not be connected to the installation network. Because the system is continuously running, the system should be protected from outside phone line interference, lightning, and power fluctuations with the necessary uninterrupted power source, UPS. Once the PC loses power, the retrieval application closes and the PC must be manually restarted. Once this is done, the application will automatically acquire data that had not been retrieved and update the data files.

Due to the continuous operation of the retrieval system, the system's hardware should be periodically reviewed for potential problems. Items to be monitored include the power supply and its cooling fan, the processor's cooling fan, the system's hard drive, and any interface cables. Periodic system integrity checks can be performed on the modem as well.

The datalogger's internal memory buffer will retain some data but it is advisable to perform periodic data backup of the retrieval system's hard drive. This can be written to a CD-RW on a routine basis for three to four weeks with no loss of data.

If data transmission from the field station is via cell phone, it is advisable to ascertain that appropriate cell phone coverage is available for the sites selected prior to purchasing and installing equipment. Two types of cell phone transmission are available, analog and digital. Analog would be preferred as it allows the use of 3-watt transmitters, which increases the available range; however, analog service is slowly being phased out to eventually be replaced by digital. Typical digital service is limited to 300 milliwatts but power amplifiers will boost the

signal. This approach could be used, but it would increase the power demand on the station power supply.

Data Quality Check. As mentioned in the “Data Retrieval Problems” section, data are retrieved daily via cell phone from the ten meteorological stations and Sally Branch water station to a desktop computer. When possible, data are reviewed on a near daily basis to monitor any problems. Each parameter of each data file is observed in a graphical form that would highlight problems and any erroneous data. Data outside of the sensor limits are automatically tagged with an error code, which can be interpreted as a null value in data analysis. Further examination of specific parameters assures the quality of the data prior to inclusion in the data repository. This initial quality check is primarily utilized as a maintenance and troubleshooting tool for the data acquisition system’s condition, but the process ultimately provides the opportunities for final error checking and annotation.

Final error checking is similar to the daily process, but uses the entire month’s data file. Once the final data check has been performed and errors or outliers have been annotated, the data file is tagged with the appropriate file name and transferred for inclusion to the data repository.

Equipment Costs. As illustrated in Table 1, equipment costs per site for the suggested meteorological equipment total approximately \$9,700. The equipment is available “off the shelf” with a customary lead time of approximately 30 days from order placement. The noted supplier, Campbell Scientific, Inc., (CSI), provides a broad selection of readily available hardware and sensors configured for direct installation into their dataloggers. This eliminates potential sensor interface development problems and conflicts and saves time engineering sensor compatibility. CSI also provides a responsive technical support team with expertise in each specific environmental discipline.

Table 2 lists the equipment costs for the surface water monitoring sites. These stations record level, flow, and temperature, and are relatively straightforward, with the package cost totaling less than \$7,000 per site.

Table 3 lists the equipment used to perform biweekly surface water quality monitoring and collection. The price of \$7,600 reflects the datasonde in its present configuration. A suite of different sensors for other parameters could be assembled with the cost remaining roughly the same.

Table 4 lists the cost of the pressure sensor used to monitor the ground well sites across the installation. The conflicts noted in the “Lessons Learned” section concerning this sensor were addressed and resolved; since then, this sensor has performed well. The sensor cost of approximately \$1,800 includes the necessary software for sensor configuration, installation, system status monitoring, and data retrieval via the interface cable to a laptop.

Site Visit Costs. To collect and maintain quality supportive data requires regular site visits to ascertain sensor function and equipment condition. Specific station problems are usually observed in the routine data quality check and the appropriate remedy is applied. After a brief training session, the site coordinator or assisting personnel can handle most problems discovered

by this method. More serious problems involving datalogger function, sensor replacement with calibration, and communication equipment repair or replacement will be addressed by specifically trained technicians. With that broad range of technical capabilities identified, placing costs on a site visit will vary from less than 1 man-hour to an extreme of 4 man-hours of on-site time. As described in the ‘Labor Costs’ section below, a senior grade electronics engineering technician is required at a minimum to perform these tasks and assure successful implementation.

Data Retrieval Costs. Data retrieval is accomplished with the assistance of communication software available from the datalogger manufacturer. The software application can be configured in numerous ways to meet hardware profiles, schedules, or other considerations. Automated collection schedules are programmed to call each station once a day and append the uncollected data to the appropriate existing file.

After installation of hardware, service arrangements are made with an area cell phone provider. Currently at Ft. Benning, Verizon is the service provider. Examination of needed service and elimination of unnecessary options for each account resulted in assignment of numbers for 13 phones at a cost of approximately \$25 per month with a 100-minute-per-month base allotment per phone. An average call takes less than 1 min, but the minimum time a call can be billed is 1 min. At present there are three authorized callers to the meteorological sites, which brings us close to the 100-minute-per-month threshold. Very seldom are overages encountered, these being caused by station problems that are explored using the call-up option or the necessity of a second or third call to complete the download.

As mentioned earlier, analog phones were installed with these systems and have served the project well. The cell phone industry is phasing out analog technology in favor of digital and the older analog phones will be replaced. Verizon will begin to phase out their analog service in the coming months at a cost of approximately \$800 per station for hardware. Service plans will need to be reviewed to determine the most cost-effective option and phones will be programmed and assigned. This change will likely impact the current cost of \$25 per month per site.

The cell phones used are assigned the local area code and are called from ERDC using the official long distance access code.

Labor Costs. Field station deployment, data acquisition and communication equipment installation, operation, and programming require knowledge of the techniques, theories, and characteristics of electronics. Sensor selection, system assembly, and system installation require knowledge involved in engineering functions such as design, development, evaluation, testing, installation, and maintenance of electronic equipment. Knowledge of the capabilities, limitations, operations, design characteristics, and function of a variety of types and models of electronic equipment and systems is essential in providing a quality data product. Familiarization with site selection criteria, sensor performance and constraints, and specific sensor usage all combine to provide the training and experience necessary to assure efficient operation of the total data acquisition system. That having been said, labor costs should be estimated with the expense of a senior electronics/engineering technician as the majority of the cost to establish, repair, and maintain these systems.

SUMMARY: For the initial four years of the long-term monitoring initiative study, a significant learning curve has occurred in the areas of large-scale data acquisition system installation, sensor performance, and remote data retrieval. This technical note illustrates the progress and experiences of the ECMI project and presents examples of data acquisition systems deployed in the remote field, as well as problems and solutions encountered.

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